Soft Contact Lens Wear at Altitude: Effects of Hypoxia

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In the U.S. Air Force, aircraft can be divided into two categories—those with cabin pressures equivalent to high altitudes and aircraft with cabin pressures equivalent to lower altitudes, with longer duration exposures. The purpose of this study was to determine the effects of soft contact lens wear under atmospheric pressures simulating these two types of aircraft environments. Ten subjects were tested to 7620 m (25,000 ft) in hypobaric chamber flights of 75 min and eight subjects were tested in hypobaric chamber flights at 3048 m (10,000 ft) for 4 h. Four subjects were also tested in dry air to further simulate cabin conditions. Vision and physiologic response were monitored by measurements of visual acuity, contrast sensitivity, and slit-lamp biomicroscopy examinations. The results of this study indicate that the physiologic responses of the cornea to soft contact lens wear at altitude are subject to higher levels of manifested stresses, but these occurred without measurable degradation in vision and did not preclude normal wear of soft contact lenses.

SINCE THE CORNEA is an avascular tissue, its primary open-eye source of oxygen is from the ambient air. At sea level, the oxygen partial pressure of this source is approximately 155 mm Hg but this pressure decreases rapidly with increasing altitude. For instance, at an altitude of 3048 m (10,000 ft), the oxygen partial pressure is reduced to 109 mm Hg and at 7620 m (25,000 ft) is 59 mm Hg. A contact lens placed between this source and the cornea must possess sufficient oxygen transport to meet a critical anterior corneal requirement to prevent hypoxia and permit a normal state of corneal hydration. Without an adequate oxygen level, edema sets in with a resulting loss in corneal transparency (23). Individuals with corneal edema may complain of foggy or hazy vision, discomfort, and injection of the conjunctiva (2). If the edema is severe, breakdown of some of the epithelial cells from prolonged lack of normal corneal metabolism is likely. This breakdown can be detected during a slit-lamp examination with the instillation of sodium fluorescein, where small spots of fluorescein staining will be seen scattered over the central corneal surface (3).

Numerous anecdotal reports, letters, and surveys have appeared in the literature describing contact lens wearers' discomfort during aircraft flights (6,8,9,15). Many investigators have speculated that the hypoxic air associated with low atmospheric pressures in flight could be the cause of this discomfort (7,12,19,20). The dryness of the aircraft cabin air has also been implicated as a possible cause (10) of significant contact lens dehydration (1) and subsequent loss of oxygen transport, since water is the primary conduit for oxygen passage through the lens (22).

USAF aviation can be divided into two systems on the basis of aircraft cabin environments. In the first system, the high-performance or fighter-attack-reconnaissance (FAR) aircraft, the aviator's eyes may be exposed for short periods to atmospheric pressures equivalent to high altitudes approaching 7620 m (25,000 ft). In the second system, the tanker-transport-bomber (TTB) aircraft, the aviator's eyes are exposed to lower equivalent altitudes, such as 1524–3048 m (5,000–10,000 ft), but typically for longer periods.

The purpose of this study was to determine the consequences of wearing soft contact lenses in these two types of aircraft environments and their corresponding reduced levels of oxygen. Accordingly, subjects who wore soft contact lenses were exposed to hypoxic conditions induced by low atmospheric pressures in a hypobaric chamber. In addition,

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a preliminary investigation of the combination of dry air and low atmospheric pressure was included to further simulate actual inflight environments.

METHODS

Fighter-Attack-Reconnaissance Aircraft Simulated-Altitude Study. Ten subjects, from whom informed consent was obtained, participated in this study which simulated cabin pressures in FAR aircraft. All subjects were fitted with two types of soft contact lenses selected from a range of low-, medium-, and high-water-content lenses. One of the 10 subjects was a unilateral contact lens wearer. Each subject was tested two times with each of the two lens types, for a total of four exposures per subject.

Altitude testing was done in a hypobaric chamber, where temperature was maintained at 21°–25°C and relative humidity was maintained at 40–50%. Subjects breathed supplemental oxygen through oronasal masks. The ascent rate was 1524 m (5,000 ft) per minute; an atmospheric pressure equivalent to an altitude of 2438 m (8,000 ft) was maintained for 30 min, followed by an altitude of 7620 m (25,000 ft) for 30 min. Descent from 7620 m was at a rate of 1524 $m \cdot min^{-1}$ with 5-min stops every 1524 m.

Monocular distant visual acuities (measured on a Bausch & Lomb Visual Testing Apparatus), subjective responses to eye comfort and vision clarity, and slit-lamp examinations were performed preflight, twice at 2438 m, and 7620 m, every 1524 m on descent, and postflight.

Tanker-Transport-Bomber Aircraft Simulated-Altitude Study. Eight subjects, from whom informed consent had been authorized, volunteered for this study of 4-h hypobaric chamber flights at an atmospheric pressure level equivalent to 3048 m (10,000 ft), simulating cabin pressures in TTB aircraft. Each subject was tested in two chamber flights—one while wearing a soft contact lens (Table I) and the other while wearing spectacles. The soft contact lenses were various types of FDA-approved extended-wear lenses, but were primarily worn on a daily-wear basis. During the flights, temperature was maintained at 21°–25°C and relative humidity was maintained at 35–50%.

Monocular distant visual acuities, as measured on a Bausch & Lomb Visual Testing Apparatus, were recorded every 30 min. Contrast sensitivity measurements were recorded before flight and at 3 and 4 h into flight using Vistech near contrast charts (Vistech Consultants, Inc., Dayton, OH) with five spatial frequencies of 1.5, 3, 6, 12, and 18 $cycles \cdot deg^{-1}$. Subjects graded their eye/lens awareness and vision clarity every 20 min on the grading scale in Table II. A slit-lamp examination was performed every 30 min to document contact lens fitting characteristics and grade (as shown on the scale in Table II) the level of conjunctival injection and tear quality factors, such as the amount of tear debris, wetability of contact lens surface, and the amount of lens deposits. Postflight slit-lamp examinations included the instillation of sodium fluorescein.

TABLE I. SOFT CONTACT LENS TYPES WORN DURING HYPOBARIC CHAMBER TESTING

Subject	Lens
1	55% H_2O Bufilcon A
2	71% H_2O Perfilcon A
3	71% H_2O Perfilcon A
4	55% H_2O Bufilcon A
5	38.5% H_2O Crofilcon A
6	38.5% H_2O Crofilcon A
7	55% H_2O Bufilcon A
8	71% H_2O Perfilcon A

Tanker-Transport-Bomber Aircraft Altitude Study and Low Humidity. Four subjects, from whom informed consent was obtained, participated in this study. Testing was performed in a hypobaric chamber under four environmental conditions: ground-level atmospheric pressure levels with 50% relative humidity; ground-level atmospheric pressure levels with 5% relative humidity; 3048-m (10,000-ft) atmospheric pressure level with 50% relative humidity; and 3048-m atmospheric pressure level with 5% relative humidity. In each condition, the subjects were tested with three modes of optical correction: spectacles, high-water-content (71%) soft contact lenses, and low-water-content (45%) soft contact lenses. Chamber temperature was maintained at 21°–25°C.

Monocular distant visual acuities were measured on a Bausch & Lomb Visual Testing Apparatus preflight and every 30 min during the chamber testing. Subjects graded the clarity of their vision and their eye/lens awareness every 30 min on the scale in Table II. At the same time intervals, slit-lamp examinations were performed to document contact lens fitting characteristics and to grade the level of conjunctival injection and tear quality. Postflight testing consisted of slit-lamp examinations, which included the instillation of sodium fluorescein, and contact lens hydration measurements to check for lens dehydration as a result of low humidity. The hydration measurements were done with a hand-held refractometer that approximated the lens water content from the measured refractive index (5).

RESULTS

Fighter-Attack-Reconnaissance Aircraft Simulated-Altitude Study. During all 40 trials (10 subjects tested twice each with two lens designs), visual acuity was not reduced from baseline levels at any time during the chamber flight. None of the 10 subjects reported any subjective change in their vision or any discomfort from the exposure to the low atmospheric pressures. Slit-lamp examinations did not reveal any significant contact lens fitting characteristics or physiological changes from baseline as a result of low atmospheric pressure.

Tanker-Transport-Bomber Aircraft Simulated-Altitude Study. Visual acuities, measured during the 4-h, 3048-m altitude exposures with both contact lenses and spectacles, were 20/20 or better throughout the chamber flight. However, visual acuity line fluctuations did occur (i.e. 20/17–20/20) a total of 19 times (6 of 8 subjects) with contact lenses and 12 times (4 of 8 subjects) with spectacles. Table

TABLE II. SUBJECT GRADING SCALE FOR SYMPTOMS AND EXAMINER GRADING SCALE FOR SLIT LAMP FINDINGS

0 = None/normal
1 = Minimal
2 = Moderate
3 = Severe
4 = Extreme/remove lenses

TABLE III VISUAL ACUITIES DURING HYPOBARIC CHAMBER TESTING FOR 4 H AT 3048 MS (10,000 FT)

Subject	Number of Visual Acuity Line Changes		Visual Acuity Ranges	
	Contact Lenses	Spectacles	Contact Lenses	Spectacles
1	4	4	20/17–20/20	20/15–20/17
2	1	2	20/15–20/17	20/12–20/15
3	2	0	20/15–20/17	20/12
4	6	3	20/15–20/17	20/15–20/17
5	0	0	20/12	20/15
6	0	0	20/15	20/15
7	2	3	20/17–20/20	20/17–20/20
8	4	0	20/12–20/15	20/15

III lists the number of line fluctuations and the range for each subject with both contact lenses and spectacles.

Baseline contrast sensitivity measurements comparing spectacles to contact lenses, as shown in Fig. 1, revealed a statistically significant difference ($p < 0.10$) only at the highest spatial frequency of 18 cycles•deg^{-1}. Contact lens contrast sensitivities after 3 h and 4 h in hypoxic conditions were not statistically different from baseline values.

Subjective grading of vision clarity was unchanged from baseline levels for all subjects during chamber flights with both contact lenses and spectacles. Subject grading of eye/lens awareness showed a trend toward more awareness among contact lens wearers, where all graded at least one eye at the grade 1 level.

Slit-lamp examinations of the contact lens wearers showed an initial rise with the average response approaching grade 1 at 1 h of flight in the examiner-graded level of tear quality factors, and remained nearly the same through the end of the chamber flight. There was a slower, less-pronounced rise during the flights with spectacles.

Conjunctival injection did increase substantially for contact lens wearers, with 6 of 8 subjects at the Moderate grading scale level at the end of the 4-h period (Fig. 2). Vertical corneal striae were detected in both eyes of one subject with contact lenses at 4 h, and were not noted when the same subject wore spectacles. Postflight slit-lamp examinations detected superficial corneal sodium fluorescein staining in 5 of 16 eyes from the contact lens flight and in 2 of 16 eyes from the spectacle flight.

Tanker-Transport-Bomber Aircraft Altitude and Low Humidity Study Visual acuity, for all subjects under all test conditions, remained 20/20 throughout the chamber flight; however, line fluctuations (i.e. 20/17–20/20) did occur with both contact lenses and glasses, (Table IV) but were more frequent with contact lenses. Exposure to low humidity with contact lenses did not produce any notable changes in the number of fluctuations, whereas spectacle testing showed an increase. Exposure to low atmospheric pressure resulted in higher frequencies of fluctuations for spectacles and both types of contact lenses. Subject grading of vision clarity was unchanged from baseline levels in all the environmental conditions tested. All subjects graded an increase to grade 1 for eye/lens awareness with contact lens wear in low humidity at ground level and for both humidities at altitude. The grading of eye awareness with spectacles increased to grade 1 for one-half the subjects during both humidity conditions at 3048 m.

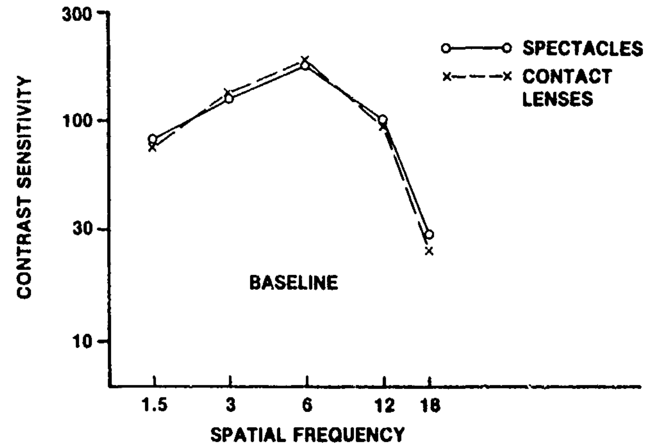

Fig. 1. Mean baseline contrast sensitivity functions for spectacles and contact lenses. Spatial frequency is in cycles per degree.

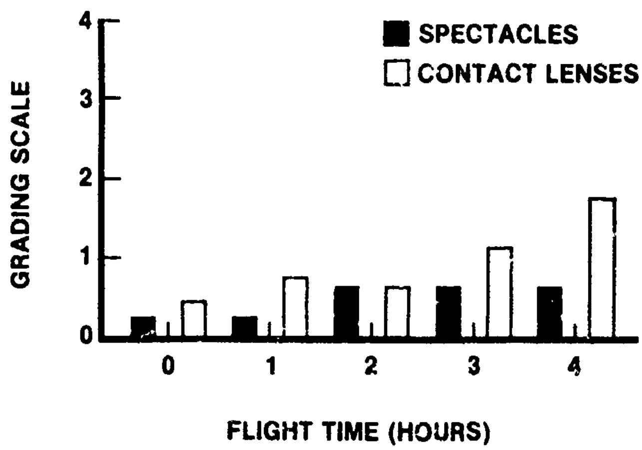

Fig. 2. Mean changes in conjunctival injection during the 4-h hypobaric chamber flights.

TABLE IV NUMBER OF VISUAL ACUITY LINE FLUCTUATIONS.

	Relative Humidity	71% H_2O Contact Lens	45% H_2O Contact Lens	Spectacles
Ground level	50%	12	17	0
	5%	12	13	5
3048 m (10,000 ft)	50%	18	21	3
	5%	19	19	15

Slit-lamp examinations of contact lens fitting characteristics did not detect any changes during any of the chamber tests. Examiner grading of tear quality factors showed an increase to the minimal level (grade 1) for 75% of the subjects during testing of contact lens wear at ground level with low humidity, and for contact lenses and spectacles at altitude with both high and low relative humidity. Grading of conjunctival injection at 3048 m showed large increases for contact lenses, greatest at 5% relative humidity, where 75% of the subjects were grade 2 (Fig. 3). For both conjunctival injection and tear quality, there was no notable difference between the low-water-content and high-water-content contact lenses.

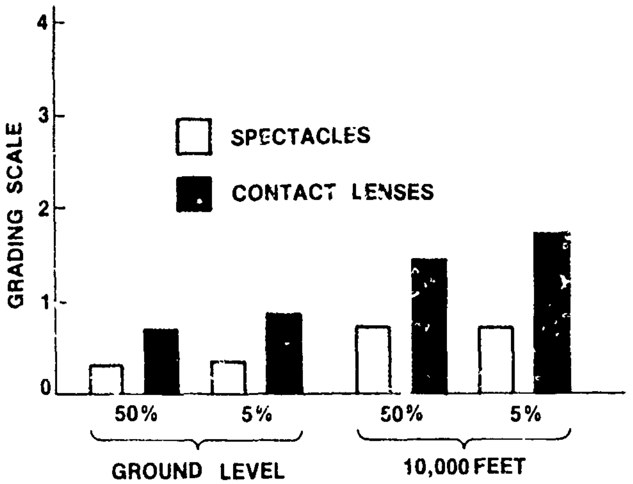

Fig. 3. Mean changes in conjunctival injection at the end of four hypobaric chamber flights at ground level and an altitude of 3048 m with 50% and 5% relative humidity levels.

TABLE V POSTFLIGHT SODIUM FLUORESCEIN STAINING.

	Ground Level		3048 m (10,000 ft)	
	Relative Humidity			
	50%	5%	50%	5%
45% H_2O Lens	1 (13%)	4 (50%)	3 (38%)	4 (50%)
71% H_2O Lens	1 (13%)	1 (13%)	2 (25%)	4 (50%)
Contact Lens Total	2 (13%)	5 (31%)	5 (31%)	8 (50%)
Spectacles	0	1 (13%)	0	1 (13%)

Table V summarizes the findings of postflight slit-lamp examinations with the instillation of sodium fluorescein, which shows a greater number of eyes with superficial corneal staining from contact lens wear under dry air conditions at ground level and under both high and low humidities at altitude than the considered optimum condition of 50% relative humidity at ground level. Table VI lists the average contact lens hydration levels at the end of the 4-h tests. The values listed are relative to the full hydration level, as measured with a hand refractometer, of two new 45% and 71% water-content contact lenses. Each new lens was measured 6 times and averaged 72.6 ± 0.8% water for the 71% labeled lens and 43.8 ± 0.4% water for the 45% labeled lens. Hydration levels for both lens types were reduced 1–1.5% at the lower humidity level, which is statistically significant ($p < 0.10$).

DISCUSSION

Hypoxic levels from low atmospheric pressures that may result in corneal edema with contact lens wear can be predicted through the use of equations derived by Fatt and St. Helen (11). These equations can be used to calculate the oxygen tension at the contact lens-cornea interface, given the oxygen uptake of the cornea, the oxygen transmissibility measured under standard conditions, and the thickness of the contact lens. Using these equations with the various air-oxygen tensions at altitudes, contact lens manufacturers' stated values of oxygen transmissibility and thickness, and the Polse-Mandell (20) criterion for the minimum precorneal oxygen to prevent edema, maximum edema-free altitudes can be estimated for contact lens wearers. Fig. 4 shows the maximum edema-free altitudes for various contact lenses ranging from low-water-content lenses to high-water content lenses with their typical center thickness. Also shown in this figure are the altitudes where 5% corneal edema is predicted, based upon anterior corneal oxygen levels found by Holden *et al* (14) to produce this level of edema. Five percent corneal edema was selected since it is only slightly greater than the normal level caused by overnight sleep in eyes without contact lenses (17,18). As shown in Fig. 4, all lenses listed are predicted to exceed 3048 m without hypoxia-induced corneal edema, and none to reach the 7620-m level without edema of less than 5%.

TABLE VI AVERAGE CONTACT LENS HYDRATION LEVEL

	45% H_2O	71% H_2O
50% Relative Humidity		
Ground level	94.4 ± 2.1%	92.5 ± 3.8%
3048 m (10,000 ft)	94.8 ± 2.0%	92.6 ± 3.1%
5% Relative Humidity		
Ground level	93.5 ± 1.5%	90.4 ± 1.0%
3048 m (10,000 ft)	93.3 ± 2.4%	91.2 ± 1.0%

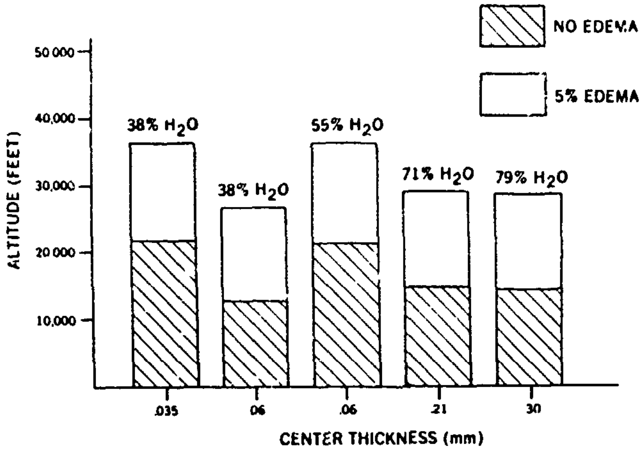

Fig. 4. Predicted altitudes that would induce corneal edema for various soft contact lenses identified by their water contents and typical center thicknesses.

To simulate aircrew flying in high-performance aircraft, contact lens wearers using supplemental breathing oxygen were exposed to a high cabin altitude of 7620 m. In this brief exposure to a low atmospheric pressure, and the associated hypoxic conditions to which the eyes were subjected, no significant adverse effects on vision, corneal physiology, or soft contact lens wear were detected.

Tanker-transport-bomber-type aircraft cabin atmospheric pressure levels were simulated in a hypobaric chamber at a pressure equivalent to 3048 m, an altitude slightly higher than commonly found in these types of aircraft. Soft contact lens vision was unaffected by this altitude exposure, even in dry air. Although visual acuity line fluctuations were frequent with contact lenses, they could not positively be linked to low atmospheric pressure. Fluctuations also were found during spectacle wear, although to a lesser degree, and with contact lenses at ground level. Variable vision has been reportedly common with contact lenses (16), and visual acuity is a subjective measure near threshold; therefore, some individual variation is to be expected. Similarly, con-

trast sensitivity with contact lenses was unaltered due to low atmospheric pressure. The difference between contact lens and spectacle contrast sensitivities—at higher spatial frequencies—found in this study has been associated with residual astigmatism uncorrected by contact lenses (4).

Indicators of physiologic stresses on the cornea, such as tear debris, conjunctival injection, and corneal epithelial staining, showed heightened responses at altitude with contact lenses. Conjunctival injection and corneal staining are associated with hypoxia and its induced edema and, therefore, may be the result of the low atmospheric pressure, although other factors, such as dry air, may also play a role. A further indication of increased physiologic stress was the detection of vertical corneal striae in both eyes of one subject with contact lenses at 3048 m. Vertical corneal striae represent significant corneal edema (21); although edema is not predicted to occur at this altitude, the oxygen demand and swelling response of the cornea is highly individualistic (13,20).

The results indicate that the physiologic responses of the cornea to soft contact lens wear are subject to higher levels of manifested stresses at altitude than at ground level. However, the higher stress levels occurred without measurable visual degradation. The discomfort of contact lens wear in aviation described by others (6,8,9,15), may be represented in this study by the increased eye/lens awareness reported by participants, who graded it at a minimal level and found it did not interfere with normal wearing. The lack of visual degradation and significant symptoms with soft contact lens wear during exposure to low atmospheric pressure, even when combined with dry air as in this study, suggests that soft contact lenses can be worn during flying. However, it is important to note that exposure was limited and that, with prolonged or repeated exposure combined with additional aircraft environmental factors, the physiologic responses of the cornea may be severe enough to affect vision and preclude wearing soft contact lenses during flight.

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